

# New England University Transportation Center



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## Final Report

*Project Title:*

Individual differences in peripheral physiology and implications for the real-time assessment of driver state (Phase I & II)

**Project Number:**

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Note: This Final Report comprises results of Phase I and Phase II of the UTC research project, "Individual Differences in Peripheral Physiology and Implications for the Real-Time Assessment of Driver State." Phase I is Project Number MITR22-7. Phase II is Project Number MITR23-5.

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Cognitively oriented in-vehicle activities (cell-phone calls, speech interfaces, audio translations of text messages, etc.) increasingly place non-visual demands on a driver's attention. While a driver's eyes may remain oriented towards the road, attention may be diverted elsewhere, resulting in decreased situational awareness, inattentive blindness, or situations of "look-but-fail-to-see" (Kass, Kerstan, & Stanny, 2007; Recarte & Nunes, 2003; Strayer, Drews, & Johnston, 2003). Physiological measures have long been established to change with escalating workload in aviation environments (Bucks & Seljos, 1994; Veltman & Gaillard, 1998). At the onset of this project, the degree to which different physiological measures are sensitive to changes in driver workload had yet to be fully established. Mehler, Reimer, Coughlin and Dusek (2009) presents results from a simulation study that assessed the sensitivity of multiple physiological measures to changes in cognitive demand through the delayed digit recall (n-back) task. While mixed results on the sensitivity of particular physiological measures such as heart rate and skin conductance appeared in the literature (see Mehler, Reimer & Coughlin, 2012 for a comprehensive review), a series of simulation and field studies completed as part of these projects clearly demonstrates the reliability of heart rate and skin conductance as measures of driver workload and illustrate the important relationships between these measures to quantify an individual's overall level of demand. In particular, the results presented in Mehler, Reimer and Coughlin (2012) highlight the consistency of response patterns across healthy participants in their 20's, 40's and 60's. In addition to establishing the sensitivity of these measures to change in driver demand, Reimer and Mehler (2011) illustrates the highly consistent patterning of heart rate to changes in demand across simulation and field studies. While basic fixed based driving simulation does not provide the same level of cognitive demand that exists as part of real world driving (e.g. lower overall heart rate), this research demonstrated pattern of changes in heart rate from a period of single task driving to a period where the driver is engaged in a cognitive secondary task is almost identical to what would be observed if the driver was on a real road.

As a result of this effort, and other NE-UTC research (MITR21-6), the n-back task has been utilized by NHTSA, OEM's, and many international laboratories as a cognitive benchmark task. Tom Ranney (NHTSA, 2011), in his report on driver distraction, commented that the most difficult demand level studied (2-back) should be considered as a first stage threshold for an acceptable dose of cognitive demand produced by an in-vehicle system.

For further information on this research please see:

Mehler, B., Reimer, B., Coughlin, J.F. & Dusek, J.A. (2009). The Impact of Incremental Increases in Cognitive Workload on Physiological Arousal and Performance in Young Adult Drivers. *Transportation Research Record*, 2138, 6-12. Also appeared in (2009) Proceedings of The Transportation Research Board 88th Annual Meeting, Washington, DC.

**Abstract:** This study examined the sensitivity of heart rate, skin conductance, and respiration rate as measures of mental workload in a simulated driving environment. Workload was systematically manipulated by using increasingly difficult levels of a secondary cognitive task. In a sample of 121 young adults, heart rate increased incrementally with increasing task demand. Significant elevations in skin conductance and respiration rate were also observed. At the lower levels of added workload, secondary task performance was nearly perfect and changes in indices of driving performance were negligible. At the highest level of workload, all three physiological measures appeared to plateau, and a subtle drop in simulated driving performance became detectable. Taken together, the pattern of results indicates that physiological measures can be sensitive to changes in workload before the appearance of clear decrements in driving performance. These findings further highlight a role for physiological monitoring as a means to measure mental workload in product design and functionality research. They also support work exploring the potential for incorporating physiological measures of driver workload and attentional state in future safety systems.

Reimer, B. & Mehler, B. (2011). The Impact of Cognitive Workload on Physiological Arousal in Young Adult Drivers: A Field Study and Simulation Validation. *Ergonomics*, 54(10), 932-942.

**Abstract:** Physiological measures provide a continuous and relatively non-invasive method of characterising workload. The extent to which such measures provide sensitivity beyond that provided by driving performance metrics is more open to question. Heart rate and skin conductance were monitored during actual highway driving in response to systematically increased levels of cognitive demand using an auditory delayed digit recall task. The protocol was consistent with an earlier simulator study, providing an opportunity to assess the validity of physiological measures recorded during driving simulation. The pattern of change in heart rate with increased cognitive demand was highly consistent between field and simulator. The findings meet statistical criteria for both relative and absolute validity, although there was a trend for absolute levels to be higher under actual driving conditions. For skin conductance level, the pattern in both environments was also quite similar and a reasonable case for overall relative validity can be made.

Mehler, B., Reimer, B. & Coughlin, J.F. (2012). Sensitivity of Physiological Measures for Detecting Systematic Variations in Cognitive Demand from a Working Memory Task: An On-road Study across Three Age Groups. *Human Factors*, 54(3), 396-412.

**Abstract:** *Objective:* To assess the sensitivity of two physiological measures for discriminating between levels of cognitive demand under driving conditions across different age groups. *Background:* Previous driving research presents a mixed picture concerning the sensitivity of physiological measures for differentiating tasks with presumed differences in mental workload. *Method:* 108 relatively healthy drivers balanced by gender and across three age groups (20-29, 40-49, 60-69) engaged in 3 difficulty levels of an auditory presentation – verbal response working memory task. *Results:* Heart rate and skin conductance level (SCL) both increased in a statistically significant fashion with each incremental increase in cognitive demand whereas driving performance measures did not provide incremental discrimination. SCL was lower in the 40s and 60s age groups; however, the pattern of incremental increase with higher demand was consistent for heart rate and SCL across all age groups. While each measure was quite sensitive at the group level, considering both SCL and heart rate improved detection of periods of heightened cognitive demand at the individual level. *Conclusion:* The data provide clear evidence that two basic physiological measures can be utilized under field conditions to differentiate multiple-levels of objectively defined changes in cognitive demand. Methodological considerations, including task engagement, may account for some of the inconsistencies in previous research. *Application:* These findings increase the confidence with which these measures may be applied to assess relative differences in mental workload when developing and optimizing HMI designs and in exploring their potential role in advanced workload detection and augmented cognition systems.

Other publications supported through this project include:

Mehler, B., Reimer, B. & Coughlin, J.F. (2010). Physiological Reactivity to Graded Levels of Cognitive Workload across Three Age Groups: An On-Road Evaluation. Proceedings of the 54th Annual Meeting of the Human Factors and Ergonomics Society. San Francisco, CA, pp. 2062-2066.

Mehler, B., Reimer, B. & Wang, Y. (2011). A Comparison of Heart Rate and Heart Rate Variability Indices in Distinguishing Single Task Driving and Driving Under Secondary Cognitive Workload. Proceedings of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design. Lake Tahoe, CA, pp. 590-597.

Zhao, N., Mehler, B., Reimer, B., D'Ambrosio, L.A., Mehler, A. & Coughlin, J.F. (2012). An Investigation of the Relationship Between the Driving Behavior Questionnaire and Objective Measures of Highway Driving Behavior. *Transportation Research Part F: Traffic Psychology and Behaviour*, 15(6), 676-685.